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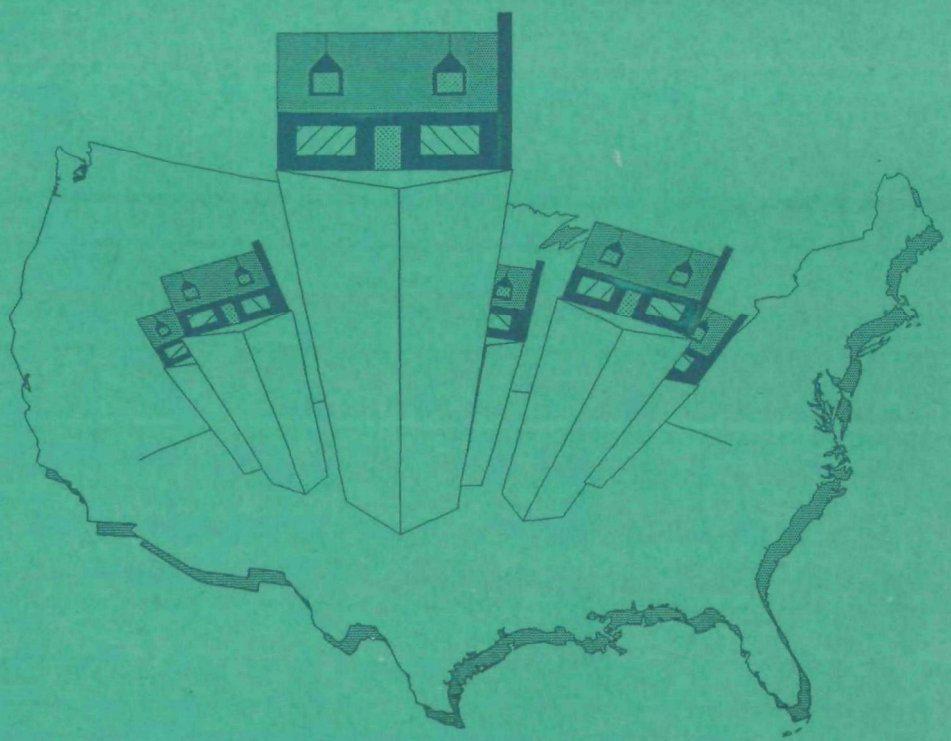
National Residential Radon Survey

Summary Report



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SUMMARY REPORT OF THE NATIONAL RESIDENTIAL RADON SURVEY

The U.S. Environmental Protection Agency (EPA) has completed its National Residential Radon Survey (NRRS). The project is the first national survey to provide an estimate of radon levels in the U.S. housing stock. The results greatly increase EPA's ability to characterize the nature and extent of the nation's indoor radon problem. The findings come after over five years of efforts to develop a survey approach, conduct field work, and carefully evaluate the results.

This summary report explains why EPA conducted the NRRS. It describes what EPA intended to learn and the survey approach. The report also summarizes the major conclusions of the study, outlines the implications of the results for the Radon Program, and discusses potential EPA initiatives for the future. The results section is divided into the following subsections: findings on the distribution of radon concentrations in the U.S. housing stock; housing and household characteristics that are central to EPA's analysis of the radon problem; and an initial assessment of the importance of certain housing characteristics in estimating residential radon levels.

WHY EPA CONDUCTED THE NRRS

In October 1986, Congress directed EPA to assess the radon levels in the nation's homes as part of a larger research effort to address a growing concern over how significant the health threat was from indoor radon. This mandate was provided in Title IV of the Superfund Amendments and Reauthorization Act (SARA).

In 1985, EPA began to recognize that elevated radon levels in homes in several portions of the country represented a serious public health threat. Homes throughout the Reading Prong area of New York, New Jersey, and Pennsylvania were registering radon levels that increased residents' chances of contracting lung cancer to greater than 1 in 10. Similar problems had been identified prior to 1985 in homes built on mining wastes from uranium and phosphorus in Colorado and Florida. In the mid-1980s, however, it had not yet become clear whether or not this problem was widespread throughout the country. The best information available at that time was a limited set of measurements of residential radon levels compiled and analyzed by scientists at the Lawrence Berkley Laboratory (LBL) in California.[1] Using these measurements, LBL estimated the annual average radon level for single family homes in the United States and the frequency distribution of radon levels in the housing stock.

Based on these results and other limited information, EPA estimated in 1986 that anywhere from 5,000 to 20,000 people per year could be dying from lung cancer caused by residential radon concentrations and that about 7 million homes had radon concentrations above levels at which EPA would recommend remedial action. Subsequently, using radon testing data provided by national testing vendors in 1986-1987, EPA analysis indicated that many more homes than originally estimated might have radon levels above the action level for radon mitigation.

Given the gravity of this situation, EPA recognized the importance of fulfilling its Congressional mandate in SARA to better define the radon problem. In 1987, EPA planned to conduct a national survey to develop a more rigorous national estimate of the distribution of radon concentrations in the U.S. housing stock. This effort was intended to focus particularly on assessing

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[1] Anthony V. Nero, et al. 1986, "Distribution of Airborne Radon-222 Concentrations to U.S. Homes", Science.

the differences in radon levels between different regions of the country and types of housing.[2] EPA also hoped to use this opportunity to conduct other crucial radon-related research that could provide a foundation for formulating effective approaches to reducing the problem.

WHAT EPA WANTED TO LEARN

Based on legislative direction and the program need, EPA established a set of primary and secondary research objectives for the NRRS that guided the development of the survey. The Agency also considered carefully the degree of precision necessary to answer critical questions about indoor radon levels and set objectives for precision levels. The Agency then established precision constraints (the amount of sampling error that would be acceptable for certain estimates of annual average radon levels) that would meet the survey objectives. The sample size and other aspects of the survey approach were developed around these precision constraints. During the survey's planning, EPA consulted with its Science Advisory Board on the survey's universe (coverage) and on how to measure annual average residential radon levels, how to select a statistically valid sample of homes, and the appropriate statistical objectives for the survey.

The primary research objectives of the survey were to estimate:

(1) The frequency distribution of annual average radon concentrations in occupied residences nationwide (to serve as the basis for estimating the national residential annual average radon level and the percentage of homes that are above levels where homeowners should take remedial action)[3]; and

(2) The frequency distributions of annual average radon concentrations in important subgroups, such as sets of states that were the responsibility of EPA's ten Regional Offices (to identify segments of the country and housing stock where radon is more likely to be a problem).[4] This data provided the basis for comparison of radon concentrations between subgroups, such as single family homes versus apartments.

Secondary research objectives included compiling housing and demographic data that could be used for radon program development and additional data that could be used to assess the relationships between indoor radon concentrations and housing construction and heating, ventilation,

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[2] EPA also undertook several other important initiatives. An in-depth assessment of EPA's risk factor for radon occurred under the auspices of the National Academy of Science and EPA's Science Advisory Board. Additionally, EPA joined with states to conduct a series of state-wide radon testing surveys that were designed to collect short-term radon measurements (e.g., screening tests) in homes that EPA could use to identify areas that have potentially high radon levels. At the end of the summer of 1992, 42 EPA/ State residential radon surveys had been completed. In addition, six states conducted their own surveys outside of this program.

[3] The Agency was interested in both the percentage of homes that have radon concentrations above its action level and the percentage of homes at very high levels where residents faced extremely high risks. The "action level" is the radon concentration where EPA recommends homeowners act to reduce their radon risks through mitigation measures.

[4] EPA administers its program activities through 10 Regional Offices that cover activities in all 50 states and the District of Columbia. Exhibit B-6 in the appendix divides the country by areas covered by EPA's Regional Offices.

and air conditioning (HVAC) characteristics. The Agency also wanted to examine how much time people spend in their homes and where they spend it. Finally, EPA saw the survey as an opportunity to see how much radon testing and mitigation the public had done.

EPA decided to set numerical precision constraints on two key estimates it wanted to obtain from the survey. These constraints also created acceptable error bounds for many other critical pieces of information as well. EPA set the following survey precision objectives:

- The national estimate of the percent of residences with radon concentrations over 10 picoCuries per liter of air (pCi/L) should have a relative standard error of no more than 0.5, if the estimate is approximately, or above 0.5 percent.[5,6,7]

- The estimate of the percent of residences with radon concentrations over 4 pCi/L for an EPA Region should have a relative standard error of no more than 0.5, if the estimate is approximately, or above 7.0 percent.

SURVEY APPROACH

EPA's primary research objectives and numerical precision constraints guided the survey's design, field work, quality assurance efforts, and analysis. The planning of the survey and pretesting took place between the beginning of 1986 and the spring of 1989. Field work (data collection) occurred between the summer of 1989 and the fall of 1990. Editing of the data, automating the data set, and the statistical analysis occurred from the fall of 1990 through the spring of 1992.

Coverage and Sampling Approach

The target population of the survey included both housing units (for radon measurements) and permanent residents of these units (for responding to the questionnaire). EPA targeted its survey toward the following population: residents whose homes were a principal residence, who had no plans to move within twelve months, and who had occupied their homes for at least nine months during the radon measurement period (partially to avoid coverage of vacation homes); and housing units not located on military installations or thinly populated areas of Alaska. The occupancy criteria were important, because the lifestyle of the residents in a home affects the radon levels present.

The survey covered all single family detached homes, multi-unit structures (e.g., townhouses, apartments, and condominiums) and mobile homes. It did not cover group quarters (e.g., college dormitories, prisons, and other types of institutional housing). Most state surveys are less comprehensive, including only single family homes (both detached and attached, such as townhouses).

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[5] A picoCurie per liter of air is a standard unit of measurement of the concentration of radioactivity in a gas. A picoCurie corresponds to 0.037 radioactive disintegrations per second in a liter of air. EPA estimates that an individual exposed to 1 pCi/L of radon over her/his entire lifetime would have a 3 in 1,000 chance of contracting lung cancer, (which is nearly always fatal).

[6] The relative standard error is the fraction of an estimate that is one standard deviation from the estimated value. There is a two to one probability that the mean value of the distribution will be within 1 standard deviation above or below the estimated mean value.

[7] Residents spending their lives in a home that has an annual average radon level greater than 10 pCi/L have greater than a one in twenty-five chance of contracting lung cancer due to radon.

The United States was partitioned into 22 strata for sampling in order to identify differences in radon levels across EPA's ten regions, and to ensure that ample coverage was provided for areas that were expected to have differing levels of radon. A multi-stage sampling process was used to select the sample. First, 125 Primary Sampling Units (PSUs), areas the size of one or more counties, were selected nationwide. Then, within each PSU, a random sample of secondary sampling units (SSUs), which were small land areas such as Census Blocks, were selected. Finally, housing units within SSUs were randomly selected to be part of the sample. This method was designed to provide a representative sample of the U.S. housing stock that would enable EPA to meet its survey objectives at a reasonable cost. The basis for the stratification of the country by differing radon levels was the best available information on radon concentrations throughout the country in 1988 when some areas still had done limited testing. Some of the assignments were made on the basis of geologic features. This has the potential for biasing the final results for each region and should be considered in evaluating the regional results.

Data Collection

EPA collected data for the survey through personal interviews with respondents and by placing radon measurement devices in their homes for one year. The personal interviews covered seventy-seven questions related to characteristics of the residents' homes, their movements within their homes, smoking habits, and steps they may have taken to test for and mitigate radon levels. EPA also assisted homeowners in placing alpha track detectors (ATDs) in their homes. These devices were selected because they were the most effective radon detectors for estimating the annual average radon levels in homes. Every floor of a home had at least one radon detector placed in an appropriate area for the measurement of that floor's annual average radon level. Two detectors were placed in appropriate locations in homes that had only one floor. Throughout the year, EPA monitored the participation of the residents involved in the study and replaced lost or damaged detectors.

Quality Assurance

Throughout the survey, EPA took numerous steps to ensure that meaningful information and measurement data were collected from the survey participants and entered properly into a data system for statistical analysis. The survey questionnaire and detector placement procedure was pretested with 60 respondents. A final questionnaire and detailed field procedures were designed based on this experience.

Standard training of interviewers for field work, data editing, and checking of questionnaire responses were performed. In addition, EPA encouraged public participation to ensure a high response rate, monitored participation by home residents on a quarterly basis, and addressed field problems with detectors as they arose. EPA also documented reasons for dropouts among participants. Detectors and detector retrieval forms were carefully checked and accounted for. EPA also ensured that the radon levels from the ATDs were accurately measured while the detectors were being "read" at the laboratory.

The Agency met the survey's precision objectives. Through its audit of data quality, EPA determined that: (1) the measurements collected could be reliably used for estimating radon levels; and (2) the response rate (after considering the reasons for nonresponse) was sufficient to meet the

precision objectives it had established.[8] EPA needed complete radon measurement information for approximately 5,000 homes in order to meet the precision constraints established in the survey objectives. To ensure that this number of reliable measurements would be obtained, the initial sample of homes drawn for the survey included 11,423 houses. This population was drawn from an eligible universe of homes (i.e., the target population,) of nearly 72 million households out of the 93 million households in the U.S. There were 7,118 respondents that initially participated in the survey by completing the survey form and placing the ATDs in their homes for measurements. When the radon detectors were retrieved and analyzed, EPA had exceeded its goal, obtaining radon measurement data from 5,694 homes and a total of over 15,000 radon detectors that had been placed in various levels within them.

The quality of questionnaire responses was also reviewed. In some cases, questions arose as to whether respondents were describing their homes properly. EPA also discovered during its review of survey responses that many residents were unable to provide accurate responses to questions regarding how members of their households spent time on different floors in their homes and how much time they spent at home in general. EPA has cautiously used the data on housing characteristics in its analysis. In its estimate of residential radon exposure, EPA based its calculations on the average radon concentration over all lived-in levels of the homes in the survey. This estimate of household radon levels was used in EPA's recent revision of its estimates of the residential risks of lung cancer to the U.S. population.[9] More information on EPA's quality assurance program is provided in Appendix A.

RESULTS OF THE SURVEY

Three types of results were obtained from the NRRS. First, EPA developed national and regional estimates of annual average radon concentrations according to different components of the housing stock. Second, EPA assembled national statistics on housing characteristics, household behavior, and the percentage of households that tested for radon and reduced their levels of exposure. Third, EPA identified housing/household characteristics that appear to most significantly affect radon levels in homes. The major results of EPA's analyses of the survey data are discussed below.

National and Regional Radon Concentrations

EPA used the measurement results from the NRRS to estimate annual average radon levels for homes throughout the United States and homes within the ten EPA Regions, as well as for different components of the housing stock. For homes covered by the survey, there were three approaches EPA considered to estimate annual averages: (1) lowest lived-in level; (2) average concentration over all lived-in levels; and (3) average concentration over all lived-in levels weighted for resident occupancy rates for different home levels. An individual's risk of getting lung cancer

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[8] The Agency also carefully considered the response levels throughout the country and weighted the data in a manner that was appropriate to draw conclusions for the entire country and the 10 EPA Regions. Details on EPA's approach can be found in U.S. EPA, 1992, National Residential Radon Survey Statistical Analysis Volume 1: National and Regional Estimates.

[9] The lived-in level is defined as an area of a home that residents spend time on a regular basis (as opposed to a storage area). The average of all lived-in levels is the simple averaging of the results for each floor that is a lived-in space. The average concentration over all lived-in levels weighted for resident occupancy rates is the average of all lived-in levels weighted by the fraction of time all residents collectively spend in each lived-in level in a home.

from residential radon exposure is directly proportional to his or her integrated exposure throughout his/her home on all levels. Therefore, the third approach represents the ideal way to assess annual averages in a home to estimate human exposure to radon levels. However, as mentioned earlier, EPA believes that many respondents were unable to provide answers to the survey questions that could form the basis for meaningful results. Therefore, **EPA used the average concentration over all lived-in housing levels to estimate the annual average radon level and other important statistics about radon levels in the housing stock.**[10]

From the NRRS, EPA estimates that:

- **Although most U.S. homes have relatively low annual average radon levels, a significant percentage of homes have levels that are much higher than ambient radon concentrations.** The median annual ambient radon level is about 0.4 pCi/L.[11] About 64 percent of all homes have annual average levels below 1 pCi/L. Of the remaining homes, 20 percent have annual average levels between 1 to 2 pCi/L and 16 percent have radon levels greater than 2 pCi/L.

- **A disproportionate share of radon exposure is in homes at higher levels.** About 56 percent of the public's residential exposure to radon occurs in homes above 2 pCi/L. Exhibit 1 shows the distribution of homes and radon exposure at various pCi/L levels in the U.S. housing stock. Exhibit 2 presents the risks individuals face at the average radon level at selected intervals within the radon distribution and EPA's recommendations for dealing with these risks.

- **The annual average radon concentration in the U.S. housing stock is 1.25 pCi/L.** EPA believes this estimate may under or overstate the average by $\pm$ 9 percent (using a 95 percent confidence interval).[12] The median value of the distribution is 0.67 pCi/L.

- **About 6 percent of U.S. homes have annual average radon levels greater than 4 pCi/L.** This radon concentration is the action level at which EPA recommends homeowners act to reduce the amount of radon in their homes. Therefore, 5.8 million homes in the United States in 1990 had radon levels that homeowners should

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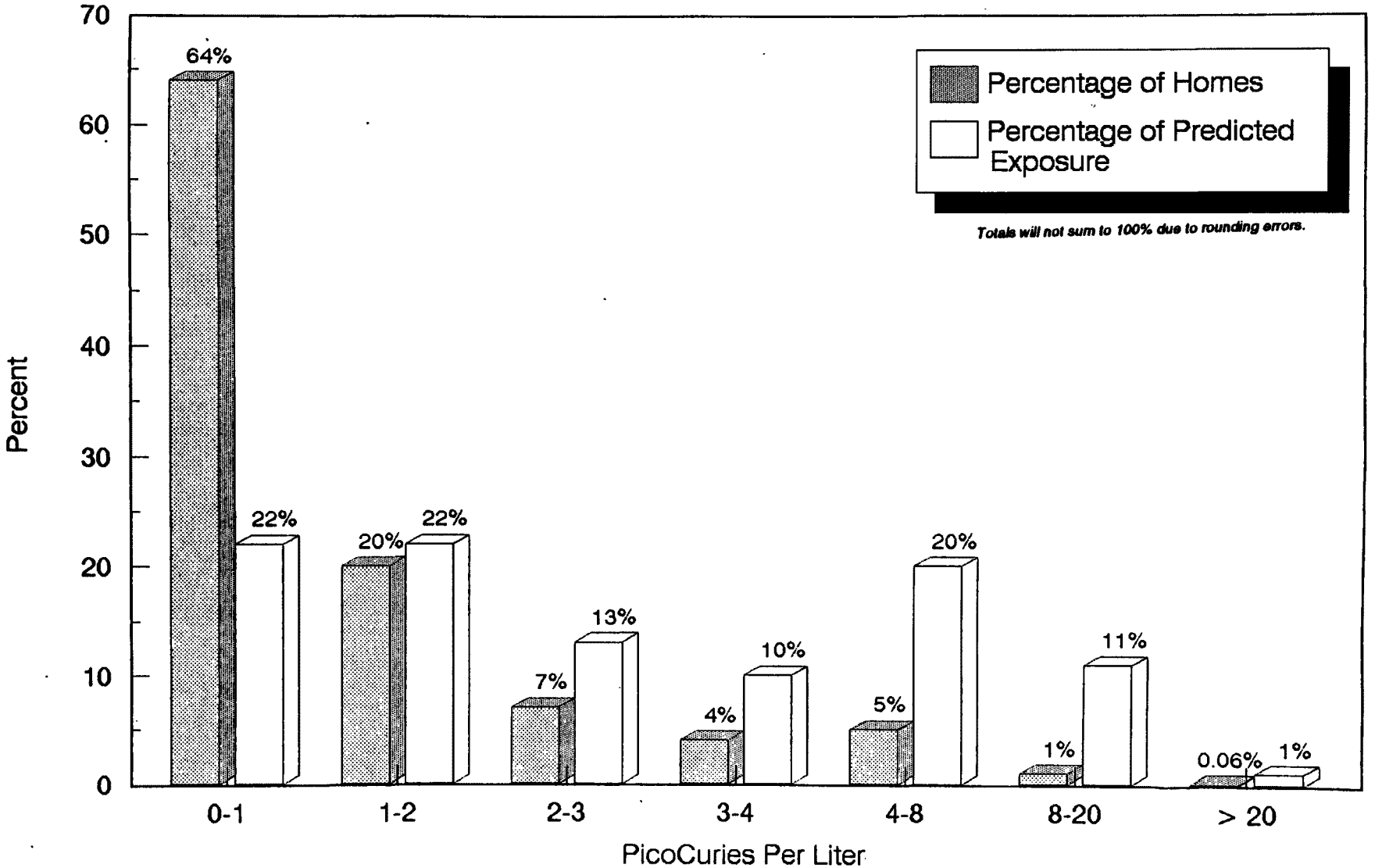
[10] To estimate the residential risks of lung cancer to the U.S. population, EPA used a range of radon concentrations around the point estimate of the national annual average radon level that was based on averaging each home's radon measurement for all lived-in levels. This annual average range was 1.1 to 1.4 pCi/L. The NRRS estimates of the annual average for the U.S. housing stock for the lowest lived-in level and the average concentration over all lived-in levels weighted for resident occupancy rates for different home levels fall within that range.

[11] Hopper, R. April 1991. National Ambient Radon Study, Proceedings of the 1991 International Symposium on Radon and Radon Reduction Technology, U.S. EPA, Office of Radiation Programs, Las Vegas Facility.

[12] The most widely accepted estimate of the national average radon level for the housing stock, which applies only to single family homes, had been 1.5 pCi/L (based on the LBL research mentioned at the outset of this report).

EXHIBIT 1

DISTRIBUTION OF HOMES AND TOTAL EXPOSURE AT SELECTED RADON LEVELS FOR ALL HOMES



Based on average over all living levels.

EXHIBIT 2

RISKS TO RESIDENTS OF HOMES AT DIFFERING RADON LEVELS AND WHAT EPA RECOMMENDS THEY DO ABOUT IT

Radon Level	If 1,000 people were exposed to this level over a lifetime...*	What EPA Recommends Residents Do
0-1	About 1 person could get lung cancer	Difficult to reduce levels
1-2	About 4 people could get lung cancer	Difficult to reduce levels
2-3	About 8 people could get lung cancer	Consider fixing home
3-4	About 11 people could get lung cancer	Consider fixing home
4-8	About 17 people could get lung cancer	Fix home
8-20	About 35 people could get lung cancer	Fix home
> 20	About 94 people could get lung cancer	Fix home

* This is the risk to the general population (including smokers, former smokers and never smokers). For 1,000 people that smoke, the column entries should be multiplied by 2.33. For 1,000 people that used to smoke, the column entries should be multiplied by 1.03. For 1,000 people that have never smoked, the column entries should be multiplied by 0.212.

mitigate.[13] This estimate of homes over 4 pCi/L may under or overstate the percentage by ± 22 percent.

- **About 0.7 percent of U.S. homes have annual average radon levels greater than 10 pCi/L.** This estimate of homes over 10 pCi/L may under or overstate the percentage by ± 54 percent.

- **Apartments or condominiums above the second floor seldom had radon concentrations above EPA's action level.** EPA does not encourage residents of apartments or condominiums (e.g., multi-unit structures) above the second floor to test. The agency recommends residents of single-family homes, multi-unit structures below the third floor, and mobile homes with permanent foundations to test for radon. Exhibit 3 shows the differences in the average annual radon levels in homes that should test and those homes the Agency does not encourage to test. It also shows estimates of the percentage of homes at levels higher than EPA's action level.

- **Single-family detached homes are four times more likely to require mitigation than multi-family homes.** The differences in radon levels between these types of housing units are shown in Exhibit 3.

- **Every EPA Region has a significant number of homes that need radon mitigation, although some Regions have much greater percentages of homes over EPA's action level of 4 pCi/L.** Each EPA Region contains anywhere from tens of thousands to more than a million homes where residents should reduce their radon levels. In two Regions, the percentages of homes over the action level were well over twice the national average of 6 percent.

More details on these and other findings on radon levels in the housing stock are provided in Appendix B.

In addition to these findings on the distribution and average levels of radon in the housing stock, EPA also examined the distributions of radon concentrations within the entire U.S. housing stock and within major components of it to determine how well they matched common distributional forms.[14] From this data, the Agency determined that **the shapes of the major radon distributions**

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[13] Based on 97.1 million single family, multi-family, and mobile homes that were regularly used (i.e., occupied year-round and not seasonally used) in the U.S. in 1990 (Census Bureau, 1991). Institutional housing units (i.e., group quarters), which were not included in the NRRS, are excluded from this estimate. They may represent another 3 million housing units at colleges, military reservations and other facilities using dormitory-style housing arrangements.

[14] The major components examined included single-family detached homes, the radon testing population, multi-family units, and ground-contact units. For all the components, except ground-contact units, see Exhibit 3 for definitions. Ground-contact units include all single-family units, except those that were 100 percent open underneath (such as unskirted mobile homes), and residences on the first floor in multi-family units.

EXHIBIT 3

COMPARATIVE STATISTICS FOR RADON LEVELS IN DIFFERENT HOUSING GROUPS

STATISTICS	ALL U.S. HOUSING POPULATION	RADON TESTING POPULATION[1]	NON-TESTING POPULATION[2]	MULTI-FAMILY HOMES[3]	SINGLE-FAMILY DETACHED HOMES[4]
Arithmetic Mean (pCi/L)	1.25	1.30	0.27	0.65	1.46
Median[5] (pCi/L)	0.67	0.71	0.19	0.36	0.79
Geometric Standard Deviation[6] (pCi/L)	3.11	3.04	4.37	3.23	2.97
Percent > 4 pCi/L	6.0%	6.3%	0.0%*	1.7%	7.1%
Percent > 10 pCi/L	0.7%	0.7%	0.0%*	0.2%	0.8%
Percent > 20 pCi/L	0.1%	0.1%	0.0%*	0.0%*	0.1%

1 EPA recommends that residents of all single-family homes, multi-unit structures (apartments, duplexes, and condominiums) below the third floor, and mobile homes with permanent foundations should test them for radon.

2 EPA does not recommend residents of multi-unit structures above the second floor to test.

3 Multi-family homes in this survey are single-family attached homes (townhouses), apartments, duplexes, and condominiums.

4 Single-family detached homes only.

5 The median value should be used as the geometric mean in conjunction with the geometric standard deviation provided below as the best parameters for estimating the lognormal distribution of radon levels for each of the survey's populations shown in this exhibit.

6 The best estimate of the GSD using a quantile approach.

* This category contains zero observations. Although homes of this type have been found with radon levels above the specified concentration, the survey results indicate that the probability of finding many of these is extremely low.

Note: The standard errors for the arithmetic means and median values can be found in Appendix B.

EPA examined from the NRRS are quite similar to the form of the lognormal distribution.[15] This is the frequency distribution that the LBL scientists believed provided the best fit for their data in 1986. However, the major national distributions resulting from the NRRS do not appear to be truly lognormal. This suggests that there could be some limitations in estimating the frequency of radon levels in both "tails" (ends) of these distributions when their parameters are simply derived from the entire data set available from the NRRS. **EPA did find that using different techniques that adjust the data and estimate the parameters of the distribution can provide a better "fit" of the lognormal to the results for different segments of the major NRRS distributions.**[16]

EPA also recognizes that conclusions can be made only for the major NRRS survey populations it examined. Other groups and subsets within the NRRS population that EPA did not examine yet may have a frequency distribution that is lognormal. In general, EPA expects that at least a strong similarity will exist, according to the present theory regarding natural generation of radon concentrations in homes. (There is a combination of many factors that lead to radon concentrations in a home, which have a multiplicative influence on one another.)

Household Characteristics

The NRRS collected information on different aspects of the housing stock and habits of residents that were relevant to EPA's development of a Radon Program. Much of these data were available from other sources such as the Census Bureau, the Public Health Service, and the Department of Energy. The reasons for collecting this data for the NRRS was that different attributes of the housing stock and household activities could be examined with respect to radon levels in the country. The next section discusses EPA's findings in the initial relational analyses of housing/household characteristics and radon levels.

Respondents to the survey were also asked if they had tested their homes for radon and done anything about it. Although other national EPA surveys have inquired about testing, the NRRS survey was the first occasion in which this data was collected nationally using personal interviews.

The highlights of EPA's findings are provided in Exhibit 4. The exhibit also provides a brief explanation of why EPA has an interest in each statistic. Further discussion of the relevance of these findings is provided below in an explanation of how EPA is using the NRRS results in the implementation of its Radon Program.

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[15] Data that are distributed lognormally, such as radon concentrations, can potentially take any positive values but cannot be zero or negative. Moreover, most data (that is, radon concentrations for most houses) are clustered near the lower end of the distribution around the mean (e.g., 1.25 pCi/L for the national residential radon distribution), with a smaller number stretching asymmetrically into a long upper "tail" in the positive direction and a short lower "tail" toward zero. In mathematical terms, a variable is said to be distributed lognormally if the natural logarithm of the variable is distributed normally--that is, with most data clustered around the mean and the rest stretching indefinitely into symmetrical "tails" in both positive and negative directions.

[16] EPA found that using the median as the geometric mean and using a quantile method for deriving the geometric standard deviation provided the parameters for a lognormal distribution that led to the best fit of a lognormal distribution to the empirical data in the NRRS.

EXHIBIT 4

MAJOR FINDINGS FROM THE NATIONAL RESIDENTIAL RADON SURVEY QUESTIONNAIRE ON HOUSING AND HOUSEHOLD CHARACTERISTICS

NRRS STATISTICS[1]	IMPORTANCE TO PROGRAM
HOUSING CHARACTERISTICS	
71% of Homes Are Single Family Detached Homes 24% of Homes Are Multi-Family Units 5% of Homes Are Mobile Units	Important to designing radon testing protocols, estimating mitigation costs, and structuring research programs for mitigation which are influenced by building type
44% of Homes Have Basements 56% of Homes Do Not Have Basements	Important for designing mitigation programs and research which are influenced by foundation type
HOUSEHOLD CHARACTERISTICS	
51% of Basements Are "Lived-in Space" 49% of Basements Are Not Lived-in Space	Important for evaluating effects of testing protocols based on placement of devices in lowest lived-in space as opposed to the lowest level in a house
2.8 Residents per Home	Critical to determining risk reductions in homes that are mitigated
20% of Residents Were Smokers 80% of Residents Were Former Smokers or Never Smoked	Radon risks are much higher for smokers than for former smokers and people who have never smoked
RADON TESTING AND ACTIONS TO REDUCE RADON LEVELS	
3% of Homes Had Been Tested by Summer 1989 97% of Homes Had Not Been Tested by Summer 1989	Indicator of radon program progress
6 to 8% of Residents in Tested Homes Had Acted to Reduce Radon Levels by Summer 1989[2] 92 to 94% of Residents in Tested Homes Had Not Acted to Reduce Radon Levels by Summer 1989	Indicator of radon program progress

[1] In all cases, except the percentage of residents that have mitigated their homes, the "don't know" responses were allocated proportionally among the other responses. For the percentage of residents that have mitigated their homes, the lower end of the range is the actual percentage of all the respondents answering "yes" and the upper end of the range is the percentage answering "yes" after a proportional allocation of the "don't know" responses has occurred between the "yes" and "no" categories.

2 The percentage range given here is the percentage of the 3 percent of homes that had tested by the Summer of 1989. The multiplying of the 6 to 8 percent of residents who have taken action to reduce radon levels by the 3 percent of homes that had tested, provides the percentage of homeowners in the entire housing stock that have done something to reduce their exposure to radon in their homes.

Housing Characteristics Associated with Radon

EPA wanted to use information collected in the NRRS to determine the relationships between selected housing characteristics and indoor radon levels. Two research objectives were established:

- Identify housing unit construction, heating, ventilation, and air conditioning (HVAC) characteristics associated with radon concentrations in U.S. housing units; and

- Ascertain their relative importance in explaining the variation in radon concentrations in the housing stock.

About 50 questions on the questionnaire were aimed at collecting the data for this type of analysis. EPA reviewed these data before using them in its relational analyses and found that some respondents had problems accurately characterizing their homes. However, EPA believed the data could be carefully used to test various hypotheses on what aspects of housing construction and HVAC systems are important in determining the level of indoor radon in a home. EPA examined the relationship between 50 different home characteristics (independent or explanatory variables) and indoor radon levels specified in different ways (dependent variables). Indoor radon level specifications included the average radon concentrations and the percentage of homes that were above 4 pCi/L and 10 pCi/L. The location of homes in areas that were considered to have high, medium, and low radon potential was used as an independent variable in one set of analyses and excluded from another. It was excluded to allow EPA to better determine what other factors might be important to the radon levels that were found in a home.

While EPA has not completed all of the relational analyses it intends to pursue, the initial analysis suggests that the most important predictor of radon levels is a home's geographic location. It further suggests that construction characteristics tend to be more important than HVAC characteristics. The independent variables found to have the most predictive value in the analyses performed are, in rank order:

- radon potential of the area;
- whether a home was a single family unit;
- whether a home had a basement entrance inside the residence;
- number of gas appliances used in a residence;
- whether a home had a basement;
- whether living space was the lowest level;
- number of months a home was closed for heating;
- foundation type;
- number of home levels; and
- amount of duct work.

EPA has not completed its examination of all the relationships between household/housing characteristics and radon levels. Therefore, it would be premature to suggest that other factors are not also important or to draw conclusions regarding the significance of various factors.

HOW EPA IS USING THE NRRS RESULTS

EPA has used results from the NRRS in a variety of different ways. The survey results have allowed EPA to establish a statistically valid national benchmark of radon levels in the U.S. housing stock, and thus have improved EPA's risk estimates. The survey's results also have provided valuable

corroborative evidence of several operating hypotheses that EPA has used to implement its program, and have assisted EPA in developing different types of radon testing protocols.

Establishing a Benchmark for Actions

One of the most important aspects of the NRRS is that it has established a Radon Program benchmark for the implementation of EPA's Radon Program. EPA has now refined its assessment of the severity of the public's exposure to radon, the types of housing units and household habits that are affected by and influence the radon problem, and measures that the public has been willing to take to address the problem. **Based on the survey, EPA believes that there are 5.8 million homes that have annual average radon levels above EPA's action level. Residents in approximately 200,000 homes had acted to reduce their radon exposures by the middle of 1989.**

Improving Risk Estimates

The most fundamental aspect of assessing the radon problem has been estimating the public health risks. The NRRS, in conjunction with other EPA efforts and the work of other external scientific organizations, has recently enabled EPA to revise its estimate of the risks from radon.[17] The Agency has used the NRRS's confidence intervals for its estimate of the annual average radon concentration and other recent EPA research to improve its quantitative estimation of the range of uncertainty in EPA's best estimate of the risk. **Given the levels of uncertainty that EPA can quantify in many of the factors contributing to the risk of radon and based on the NRRS's estimate of the annual average radon level of 1.25 pCi/L, EPA estimates that indoor radon in homes causes between 7,000 and 30,000 lung cancer deaths per year.**[18] (EPA's "best estimate" is 14,000 annual lung cancer deaths are due to residential radon exposure.)

NRRS data also have provided EPA with a better estimate of the number of homes in the United States that are well above its action level of 4 pCi/L. The previous LBL work suggested that about 1 percent of U.S. single family homes were above 10 pCi/L. The national survey provides a fairly comparable estimate that about 0.7 percent of homes are above 10 pCi/L.[19]

Providing Corroborative Evidence

The NRRS has corroborated a number of operating hypotheses that have guided the Radon Program. Most importantly, large numbers of homes with annual average radon levels greater than 4 pCi/L exist in all the EPA Regions. **This survey supports EPA's national effort to encourage all homeowners to test for radon and reduce elevated levels.**

In addition, **the relational analysis and regional radon estimates from the NRRS have shown geographic differences in the potential for elevated radon levels.** This supports EPA's strategy to facilitate the targeting of federal and state resources to areas with the highest radon potential.

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[17] EPA has improved its estimate of the risk factor largely based on the contributions of two National Academy of Science reports entitled Comparative Dosimetry of Radon in Mines and Homes (1991) and Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR IV (1990).

[18] Further information on the risks from residential exposure to radon can be found in Chapter 2 of the Technical Support Document for the 1992 Citizen's Guide to Radon, U.S. EPA, 1992. This estimate is based on a residential population estimate of 250 million people in 1990.

[19] Using a 95 percent confidence interval, the percentage of homes over 10 pCi/L may be 0.3 to 1.0 percent.

From the outset of the Radon Program, EPA has focused its mitigation research on fixing single family detached homes. There has been little research covering apartments. **The survey confirms that EPA's emphasis on developing mitigation methods for single family detached homes was correct,** because few homes with elevated radon levels were identified in multi-family homes. EPA also found that its use of statistics developed for other purposes by the Census Bureau, the Public Health Service, and the Department of Energy about housing/household characteristics, such as occupancy levels and building foundation types, were appropriate for the housing population of interest.

Influencing Testing Protocols

EPA has used NRRS results to critically evaluate different testing protocols for its 1992 Citizen's Guide to Radon and for the upcoming Home Buyers and Sellers Guide to Radon for use in real estate transactions. In this analysis, EPA considered the reliability of several testing methods, which include different types and combinations of short- and long-term tests that are used to determine the necessity of fixing a home. This effort led EPA to review and reassess the advice it had been giving the public regarding radon testing. In the past, EPA has urged the public to use long-term tests in most situations. The Agency continues to recommend long-term testing, but has developed appropriate short-term testing approaches that can be used if test results are needed quickly. EPA also believes the availability of short-term testing approaches will facilitate increased residential radon testing, because research has shown that more residents are willing to conduct short-term tests.

The NRRS data provided the frequency distribution of the annual average radon levels for homes for which the Agency recommends testing for radon.[20] EPA used the frequency distribution of radon levels as estimated by of the NRRS and other research on the accuracy of short-term radon tests to analyze the ability of different testing protocols to classify homes either above or below the action level.

FUTURE RESEARCH QUESTIONS

EPA is considering several follow-up studies based on the data collected in the NRRS. EPA plans to further investigate the significance of certain housing/household characteristics in predicting radon levels and whether they also can be considered factors that directly influence existing radon levels. In a related effort, EPA has joined with the U.S. Geological Survey and the Department of Energy in a project to develop an approach for locating areas of the country with the greatest percentage of homes with elevated radon levels. The Agency is also assessing in more detail the uncertainties of short-term tests for making mitigation decisions. As part of that effort, EPA is considering the value of future research that would:

- Investigate relationships between short and long-term measurements;
- Investigate within-year variations in the radon levels in homes;
- Evaluate the relationship among annual average radon concentrations and certain weather factors, such as rainfall; and

[20] EPA recommends radon testing by residents of single family homes, multi-unit structures (apartments) below the third floor, and mobile homes with permanent foundations.

- Evaluate and improve, if necessary and possible, the quality of questionnaire data regarding selected aspects of the survey such as occupancy data and actions to mitigate radon levels.

WHERE TO GET MORE INFORMATION

More details on the findings of this summary report and other results from the NRRS are available in reports EPA has prepared with the results of the analysis. They are:

- U.S. EPA, 1992, National Residential Radon Survey Statistical Analysis Volume 1: National and Regional Estimates.
- U.S. EPA, 1992, National Residential Radon Survey Statistical Analysis Volume 2: Summary of the Questionnaire Data.
- U.S. EPA, 1992, National Residential Radon Survey Statistical Analysis Volume 3: Housing Unit Characteristics Associated with Radon.
- U.S. EPA, 1992, National Residential Radon Survey: Field Operations Report.
- U.S. EPA, 1992, Quality Assurance Support for the National Residential Radon Survey.
- U.S. EPA, 1989, National Residential Survey Design Report.

These six reports can be obtained by contacting EPA's Radon Division at (202) 233-9380 or writing to:

National Residential Radon Survey Results
Radon Division (RD-6604J)
Office of Radiation Programs
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

APPENDIX A

QUALITY ASSURANCE

EPA prepared a Quality Assurance Project Plan (QAPP) that established standard policies, procedures, and organizational arrangements to achieve quality assurance goals that were established for the survey. The plan had procedures for data collection, sample custody, calibration, detector analysis, and data processing. It covered both the placement of the alpha track detectors (ATDs) used to record the radon levels and the laboratory's process of analyzing the results from the detectors.

The plan also had quality assurance objectives for the survey and the radon measurements. It specified goals for precision, bias, completeness, representativeness, and comparability. Goals also were established to ensure the EPA precision objectives mentioned in the text for fractions of homes > 4 and > 10 pCi/L were met. The key goals were:

- At least 5,000 homes would produce usable ATD readings (completeness goal).
- ATDs receiving monitored exposures (spikes) would have a coefficient of variation ≤ 0.20 (precision goal).
- ATDs receiving monitored exposures would have reported exposures within 15 percent of the monitored level (bias goal).
- Less than 50 percent of unexposed ATDs (blanks) would have reported exposures > 30 pCi-d/L and none would have reported exposure > 60 pCi-d/L.
- During data entry, there would be a < 0.5 percent error rate for fields containing one- or two-digit/character codes and < 5.0 percent error rate for fields containing longer text (e.g., names and addresses).

Several audits were specified in the QAPP to ensure compliance with established procedures and data quality objectives. These included formal technical system audits, performance evaluation audits, and an audit of overall data quality. In addition, less formal activities were conducted to ensure data quality. They included careful selection of the type of detectors to be used, development of detector placement guidelines, and monitoring operations at the laboratory processing the ATDs.

Based on the audits that occurred during the NRRS, EPA determined that the survey was administered satisfactorily given its data quality goals. The NRRS produced usable radon measurements in close to 5,700 homes, substantially exceeding the 5,000 home completeness goal. Exhibit A-1 shows the survey's response rates. The error rate for key questionnaire data was 0.28 percent, well within the 0.5 percent objective. The performance of the spiked and duplicate ATDs satisfied the precision and bias goals specified in the QAPP. The reported values of the blanks were higher than EPA had set for its quality assurance goals. The Agency's evaluation of this result led to the conclusion that the laboratory processing the detectors may have underestimated the background correction factor for the NRRS detectors and that the effect on annual average concentrations in most homes was small. Considering the Agency's overall performance in meeting the survey's quality assurance requirements, EPA concluded that the radon measurements could be used to achieve the objectives of the survey.

EPA identified certain problems during the survey which have led to careful use of the results to avoid reaching inappropriate conclusions from data that are identified to have limitations. For example, EPA identified potential problems surrounding the fact that certain participants did not respond to some types of questions accurately. This clearly occurred in the responses received on occupancy rates. This problem also arose for some of the questions on housing characteristics. For example, respondents had difficulty in determining whether their homes were "tight" (well-insulated and constructed to reduce exfiltration). EPA further recognizes from its auditing efforts that the fraction of homes with low concentrations (< 0.5 pCi/L) may be slightly depressed by inadequate background correction at the laboratory. EPA has analyzed the data and reported results with a sensitivity to the limitations that exist in certain portions of these NRRS data.

Exhibit A-1

Summary of Data Collection Results

Result Category	Number	Rates
Total Sample Size	11,423	
Eligibility Status Ascertained	10,961	96.0%
Eligible Cases	8,444	
Nonrespondents	1,326	
Respondents	7,118	84.3%
Eligible for Panel Maintenance	7,118	
Became Ineligible During Monitoring Period	699	
Eligible at End of Monitoring Period	6,419	
Final Nonrespondents	725	
Final Respondents	5,694	88.7%
Cumulative Detector Coverage Rate at End of Study (0.960 x 0.843 x 88.7%)		71.8%

APPENDIX B

ADDITIONAL NRRS RESULTS ON NATIONAL AND REGIONAL RADON LEVELS IN THE U.S. HOUSING STOCK

The following tables and figures provide more details on the results given in the body of this summary report and useful supplemental information. The results that follow are for the estimates of annual average radon levels for the average of all lived-in levels for year-round occupied housing units in the United States. The radon measurements were taken for one year during 1989 to 1990. The results appear in EPA's National Residential Radon Survey Statistical Analysis Volume 1: National and Regional Estimates, 1992.

In reviewing the results showing the differences between EPA Regions, it must be recognized that there is a potential for a bias that could lead to the understating of the radon levels in several Regions due to the initial selection of sampling strata for the survey on the basis of limited (although the best available) data on the variability in radon levels in different areas in each Region (see p.4 of main report). Also, the regional percentage estimates mask areas within the states in each EPA Region that may have high residential radon levels by only providing an estimate for an entire region. Therefore, the regional results should be cautiously used in drawing conclusions about the nature of the radon problem in various locations in the United States. More specific regional and state information on residential radon levels can be obtained from the appropriate EPA Regional Offices and state radiation programs.

EXHIBIT B-1

National Distribution of Annual Average Radon Levels in the U.S. Housing Stock

Average Over All Living Levels

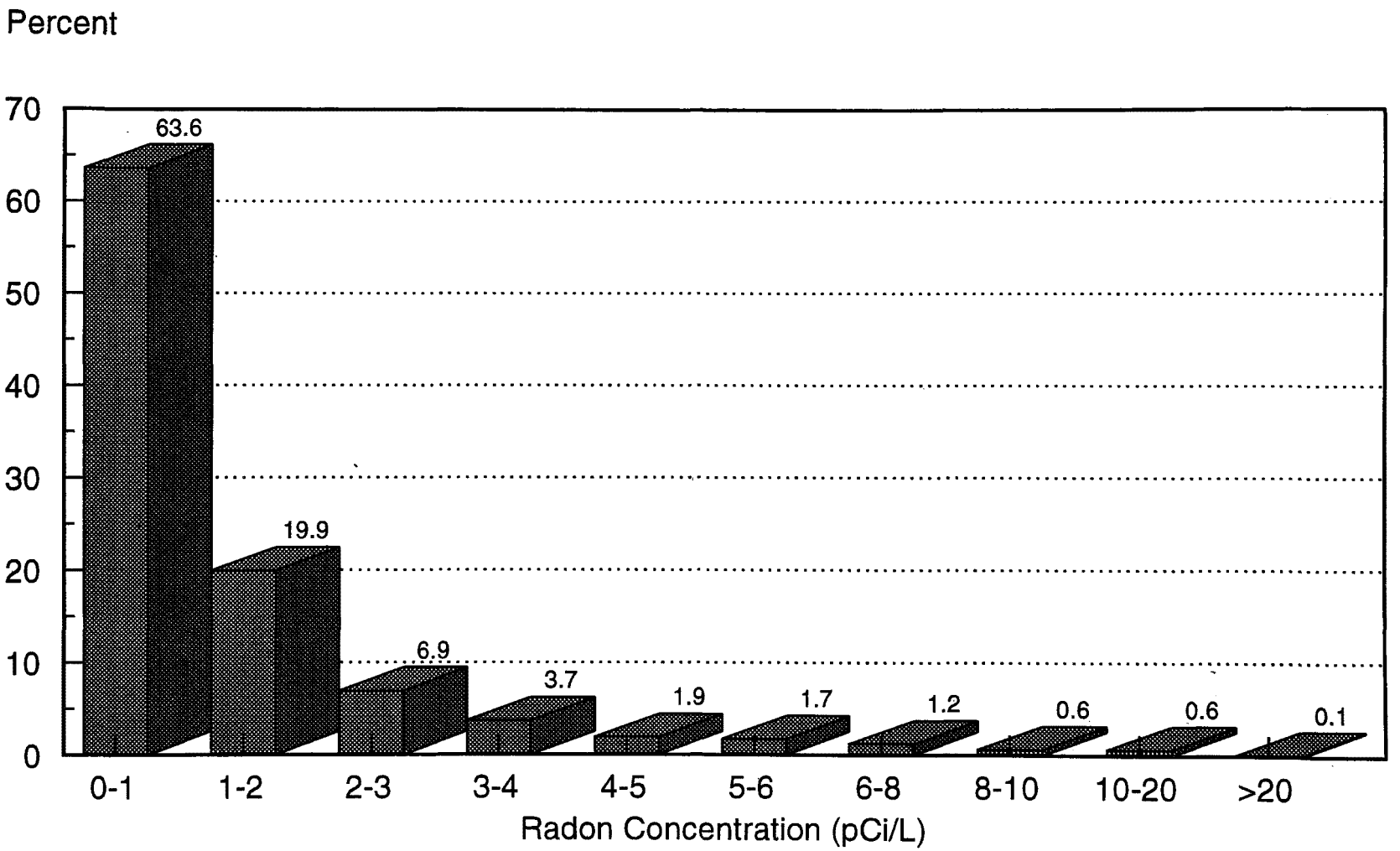


EXHIBIT B-2

ESTIMATED DISTRIBUTION OF ANNUAL AVERAGE RADON LEVELS BY EPA REGION OVER ALL LIVING LEVELS

Region\pCi/L	0-1	1-2	2-3	3-4	>4	Homes > 4 pCi/L
Region I						
Percent	**63.7**	**19.8**	**8.1**	**4.3**	**4.1**	
(Std. Err.)	(6.45)	(2.30)	(2.72)	(1.75)	(1.14)	212,000
No. of Obs.	212	77	31	16	19	
Region II						
Percent	**77.4**	**11.7**	**4.6**	**2.3**	**3.9**	
(Std. Err.)	(6.14)	(2.55)	(1.35)	(1.36)	(1.34)	382,000
No. of Obs.	495	73	28	13	23	
Region III						
Percent	**65.0**	**18.8**	**5.4**	**3.4**	**7.4**	
(Std. Err.)	(5.51)	(3.13)	(1.14)	(0.77)	(2.17)	750,000
No. of Obs.	483	176	55	33	63	
Region IV						
Percent	**66.4**	**20.9**	**5.5**	**2.4**	**4.8**	
(Std. Err.)	(3.78)	(2.51)	(0.57)	(0.47)	(1.78)	867,000
No. of Obs.	488	180	57	31	45	
Region V						
Percent	**48.0**	**24.6**	**12.0**	**6.2**	**9.2**	
(Std. Err.)	(2.53)	(1.48)	(0.79)	(0.67)	(1.56)	1,644,000
No. of Obs.	680	380	194	101	149	
Region VI						
Percent	**75.6**	**16.9**	**3.8**	**1.0**	**2.7**	
(Std. Err.)	(2.33)	(2.20)	(0.76)	(0.36)	(1.02)	303,000
No. of Obs.	293	86	18	5	17	
Region VII						
Percent	**30.4**	**31.0**	**12.4**	**9.4**	**16.8**	
(Std. Err.)	(9.72)	(3.60)	(3.78)	(2.16)	(6.94)	814,000
No. of Obs.	93	98	38	30	55	
Region VIII						
Percent	**34.0**	**23.7**	**14.0**	**8.3**	**20.1**	
(Std. Err.)	(13.06)	(3.12)	(3.99)	(2.90)	(6.13)	604,000
No. of Obs.	78	70	43	26	62	
Region IX						
Percent	**73.3**	**19.7**	**4.0**	**2.4**	**0.7**	
(Std. Err.)	(4.92)	(2.80)	(1.14)	(2.18)	(0.42)	92,000
No. of Obs.	299	72	11	5	3	
Region X						
Percent	**84.9**	**11.4**	**1.7**	**0.6**	**1.4**	
(Std. Err.)	(6.55)	(6.61)	(1.61)	(0.59)	(1.27)	50,000
No. of Obs.	131	38	13	5	3	
United States						
Percent	**63.6**	**19.9**	**6.9**	**3.7**	**6.0**	
(Std. Err.)	(1.59)	(0.88)	(0.42)	(0.39)	(0.68)	5,836,000
No. of Obs.	3,252	1,250	488	265	439	

Note: EPA designed the survey to obtain a relative standard error (RSE) (Standard error ÷ values) of no more than 0.5 for its Regional estimates of the percentage of homes greater than 4 pCi/L, if the estimate is close to 7 percent of homes. For EPA Regions I through VIII the RSEs are below 0.5. For EPA Regions IX and X the RSEs are .6 and .9, respectively. This is due to the small number of observatons found above 4 pCi/L. The relatively large standard errors for these two regions indicate there is greater uncertainty around the estimates provided in this table relative to the other Regions. The following exhibit (B-3) shows for the percentage of homes over 4 pCi/L where there are and are not statistically significant differences between regions. Numbers do not total due to rounding error.

EXHIBIT B-3

RESULTS OF AN ANALYSIS OF THE STATISTICALLY SIGNIFICANT DIFFERENCES THAT EXIST BETWEEN EPA REGIONS FOR THE PERCENTAGE OF HOMES GREATER THAN 4 pCi/L

EPA Region/ Percentage >4 pCi/L	I 4.1%	II 3.9%	III 7.4%	IV 4.8%	V 9.2%	VI 2.7%	VII 16.8%	VIII 20.1%	IX 0.7%	X 1.4%
I 4.1%	X									
II 3.9%		X								
III 7.4%			X							
IV 4.8%				X						
V 9.2%					X					
VI 2.7%						X				
VII 16.8%							X			
VIII 20.1%								X		
IX 0.7%									X	
X 1.4%										X

Key: Shaded areas show regions that do not have statistically significant differences at the 90 percent confidence level. This table is meant to be used in conjunction with the review of Exhibit B-2.

EXHIBIT B-4

ESTIMATES OF SELECTED PARAMETERS OF THE DISTRIBUTION OF ANNUAL AVERAGE RADON CONCENTRATIONS OF THE AVERAGE OVER ALL LIVING LEVELS IN THE U.S. BY RADON LEVELS

Radon Level (pCi/L)	Arithmetic Mean (pCi/L)	Median (pCi/L)
0-1	**0.43**	**0.40**
(Std. Err.)	(0.01)	
No. of Obs.	3,252	3,252
1-2	**1.40**	**1.36**
(Std. Err.)	(0.01)	
No. of Obs.	1,250	1,250
2-3	**2.44**	**2.43**
(Std. Err.)	(0.02)	
No. of Obs.	488	488
3-4	**3.43**	**3.40**
(Std. Err.)	(0.02)	
No. of Obs.	265	265
4-5	**4.45**	**4.42**
(Std. Err.)	(0.02)	
No. of Obs.	142	142
5-6	**5.47**	**5.43**
(Std. Err.)	(0.04)	
No. of Obs.	106	106
6-8	**6.90**	**6.84**
(Std. Err.)	(0.06)	
No. of Obs.	93	93
8-10	**8.95**	**9.03**
(Std. Err.)	(0.08)	
No. of Obs.	47	47
10-20	**12.89**	**11.99**
(Std. Err.)	(0.33)	
No. of Obs.	46	46
>20	**29.25**	**25.12**
(Std. Err.)	(4.80)	
No. of Obs.	5	5
Total	**1.25**	**0.67**
(Std. Err.)	(0.06)	
No. of Obs.	5,694	5,694

EXHIBIT B-5

ESTIMATES OF SELECTED PARAMETERS OF THE DISTRIBUTION OF ANNUAL AVERAGE RADON CONCENTRATIONS OVER ALL LIVING LEVELS IN THE UNITED STATES BY EPA REGION

EPA Region	Arithmetic Mean (pCi/L)	Median[1] (pCi/L)	Geometric Standard Deviation[2]
Region I			
Estimate	**1.18**	**0.69**	**2.96**
(Std. Err.)	(0.19)		(n.a)
No. of Obs.	355	355	355
Region II			
Estimate	**0.86**	**0.35**	**4.66**
(Std. Err.)	(0.19)		(n.a)
No. of Obs.	632	632	632
Region III			
Estimate	**1.37**	**0.68**	**2.76**
(Std. Err.)	(0.26)		(n.a)
No. of Obs.	810	810	810
Region IV			
Estimate	**1.14**	**0.66**	**2.62**
(Std. Err.)	(0.13)		(n.a)
No. of Obs.	801	801	801
Region V			
Estimate	**1.69**	**1.06**	**2.91**
(Std. Err.)	(0.12)		(n.a)
No. of Obs.	1,504	1,504	1,504
Region VI			
Estimate	**0.81**	**0.45**	**3.00**
(Std. Err.)	(0.06)		(n.a)
No. of Obs.	419	419	419

[1] The median should be used as the geometric mean in conjunction with the geometric standard deviation (GSD) in this exhibit as the best parameters for estimating the lognormal distribution of radon levels for each area of the country in the exhibit.

[2] The best estimate of the GSD using a quantile approach.

ESTIMATES OF SELECTED PARAMETERS OF THE DISTRIBUTION OF ANNUAL AVERAGE RADON CONCENTRATIONS OVER ALL LIVING LEVELS IN THE UNITED STATES BY EPA REGION
(continuation of EXHIBIT B-5)

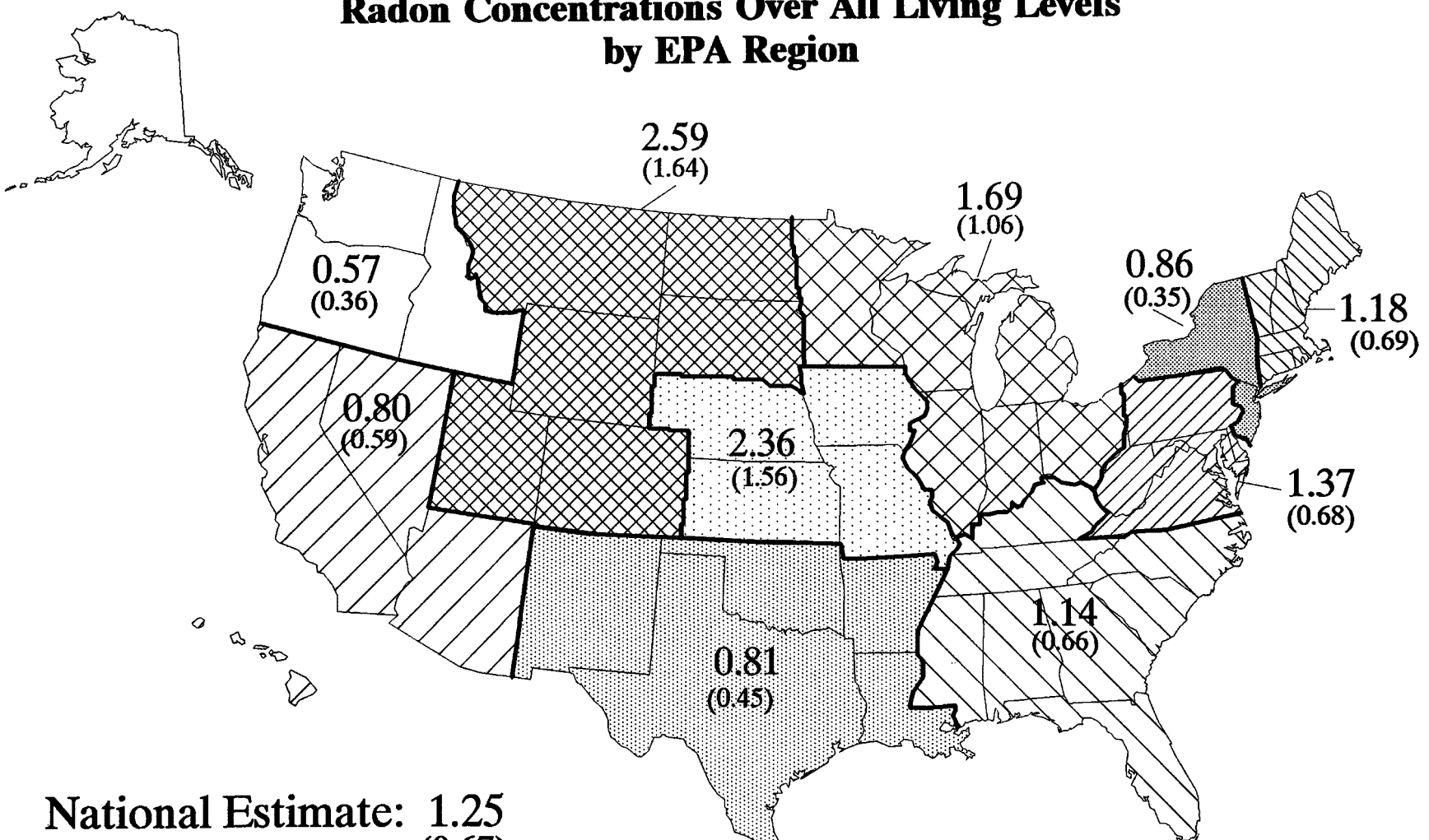
EPA Region	Arithmetic Mean (pCi/L)	Median[1] (pCi/L)	Geometric Standard Deviation[2]
Region VII			
Estimate	**2.36**	**1.56**	**2.44**
(Std. Err.)	(0.50)		(n.a)
No. of Obs.	314	314	314
Region VIII			
Estimate	**2.59**	**1.64**	**2.91**
(Std. Err.)	(0.70)		(n.a)
No. of Obs.	279	279	279
Region IX			
Estimate	**0.80**	**0.59**	**2.71**
(Std. Err.)	(0.12)		(n.a)
No. of Obs.	390	390	390
Region X			
Estimate	**0.57**	**0.36**	**2.54**
(Std. Err.)	(0.10)		(n.a)
No. of Obs.	190	190	190
United States			
Estimate	**1.25**	**0.67**	**3.11**
(Std. Err.)	(0.06)		(n.a)
No. of Obs.	5,694	5,694	5,694

[1] The median should be used as the geometric mean in conjunction with the geometric standard deviation (GSD) in this exhibit as the best parameters for estimating the lognormal distribution of radon levels for each area of the country in the exhibit.

[2] The best estimate of the GSD using a quantile approach.

EXHIBIT B-6

Arithmetic Mean (pCi/L) and Median (in parenthesis) of the Distribution of Annual-Average Radon Concentrations Over All Living Levels by EPA Region

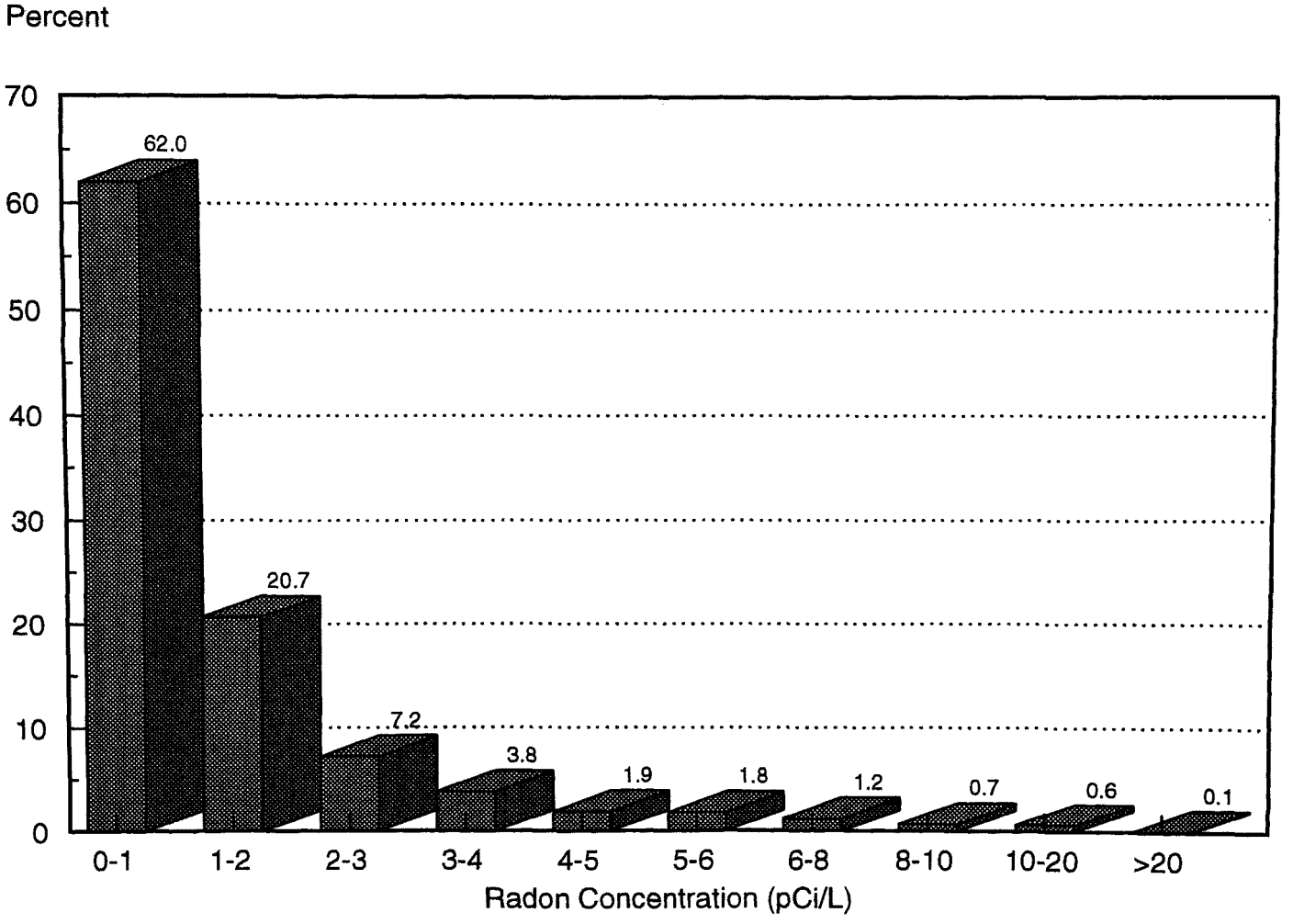


National Estimate: 1.25
(0.67)

EXHIBIT B-7

Testing Population* Distribution of Annual Average Radon Concentrations in Year-Round Occupied Housing Units

Average Over All Living Levels



* EPA recommends that residents of all single-family homes, multi-units below the third floor, and mobile homes with permanent foundations should test them for radon.

EXHIBIT B-8

ESTIMATES OF SELECTED PARAMETERS FOR INTERVALS IN THE NATIONAL DISTRIBUTION OF ANNUAL AVERAGE RADON LEVELS FOR THE AVERAGE OVER ALL LIVING LEVELS IN THE TESTING POPULATION*

Radon Interval (pCi/L)	Arithmetic Mean (pCi/L)	Median (pCi/L)
0-1	**0.44**	**0.42**
(Std. Err.)	(0.01)	
No. of Obs.	3,008	3,008
1-2	**1.40**	**1.37**
(Std. Err.)	(0.01)	
No. of Obs.	1,244	1,244
2-3	**2.44**	**2.42**
(Std. Err.)	(0.02)	
No. of Obs.	487	487
3-4	**3.43**	**3.40**
(Std. Err.)	(0.02)	
No. of Obs.	264	264
4-5	**4.45**	**4.42**
(Std. Err.)	(0.02)	
No. of Obs.	142	142
5-6	**5.47**	**5.43**
(Std. Err.)	(0.04)	
No. of Obs.	106	106
6-8	**6.90**	**6.84**
(Std. Err.)	(0.06)	
No. of Obs.	93	93
8-10	**8.95**	**9.03**
(Std. Err.)	(0.08)	
No. of Obs.	47	47
10-20	**12.89**	**11.99**
(Std. Err.)	(0.33)	
No. of Obs.	46	46
>20	**29.25**	**25.12**
(Std. Err.)	(4.80)	
No. of Obs.	5	5
Total	**1.30**	**0.71**
(Std. Err.)	(0.06)	
No. of Obs.	5,442	5,442

* EPA recommends that residents of all single-family homes, multi-unit structures below the third floor, and mobile homes with permanent foundations should test them for radon.

EXHIBIT B-9

Distribution of Annual Average Radon Levels in Single-Family Units

Average Over All Living Levels

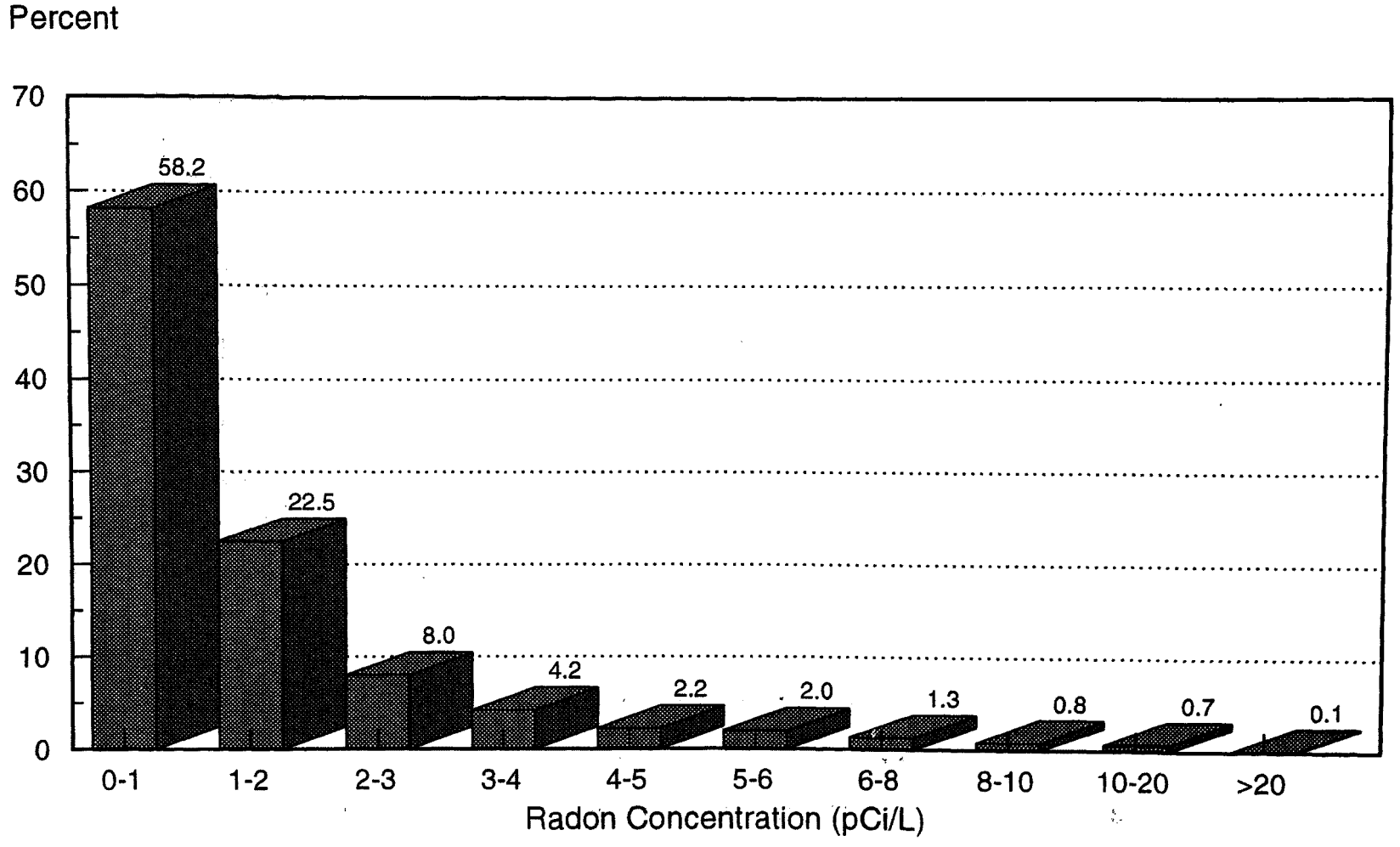


EXHIBIT B-10

Distribution of Annual Average Radon Levels in Multi-Family Units

Average Over All Living Levels

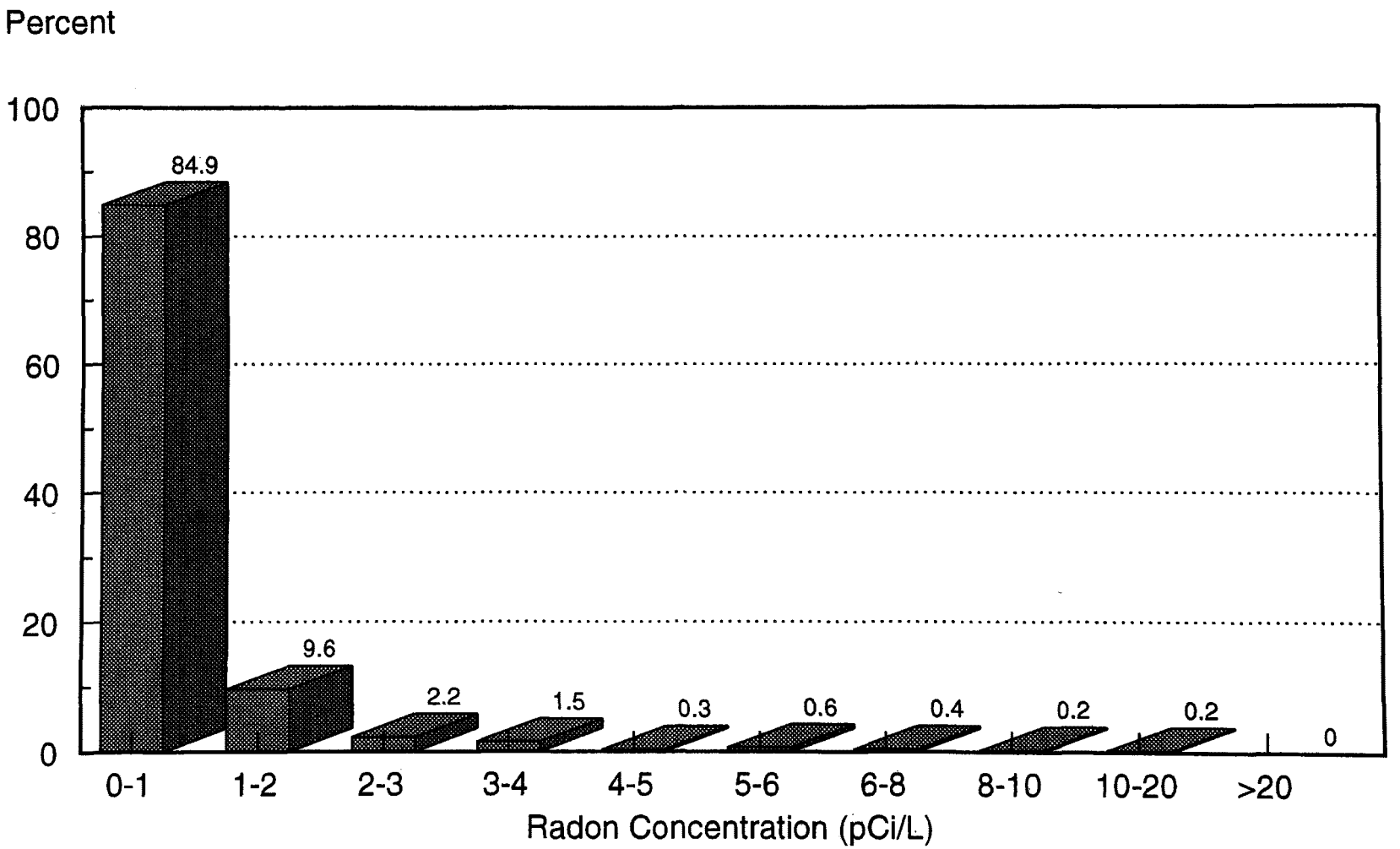


EXHIBIT B-11

ESTIMATES OF SELECTED PARAMETERS OF THE DISTRIBUTION OF ANNUAL AVERAGE RADON LEVELS IN THE UNITED STATES BY FLOOR FOR SINGLE-FAMILY HOUSING UNITS

Floor in Housing Unit	Arithmetic Mean (pCi/L)	Median (pCi/L)	Geometric Standard Deviation
Basement (Total)	**3.30**	**2.06**	**2.90**
(Std. Err.)	(0.23)		(n.a)
No. of Obs.	2,716	2,716	2,716
Basement (Living Space)	**3.07**	**1.88**	**2.93**
(Std. Err.)	(0.24)		(n.a)
No. of Obs.	1,398	1,398	1,398
Basement (Not Living Space)	**3.55**	**2.28**	**2.81**
(Std. Err.)	(0.26)		(n.a)
No. of Obs.	1,318	1,318	1,318
1st Level Above Ground	**1.31**	**0.77**	**2.84**
(Std. Err.)	(0.07)		(n.a)
No. of Obs.	4,350	4,350	4,350
2nd Level Above Ground	**1.18**	**0.70**	**2.78**
(Std. Err.)	(0.09)		(n.a)
No. of Obs.	1,561	1,561	1,561
3rd and Higher Levels Above Ground	**0.99**	**0.64**	**2.61**
(Std. Err.)	(0.16)		(n.a)
No. of Obs.	174	174	174

EXHIBIT B-12

COMPARISON OF THE NATIONAL AND GROUND-CONTACT POPULATION EMPIRICAL DISTRIBUTIONS WITH THE LOGNORMAL DISTRIBUTIONS MODELED USING THE MEDIAN AND BEST RANGE ESTIMATOR TO ESTIMATE THE LOGNORMAL PARAMETERS

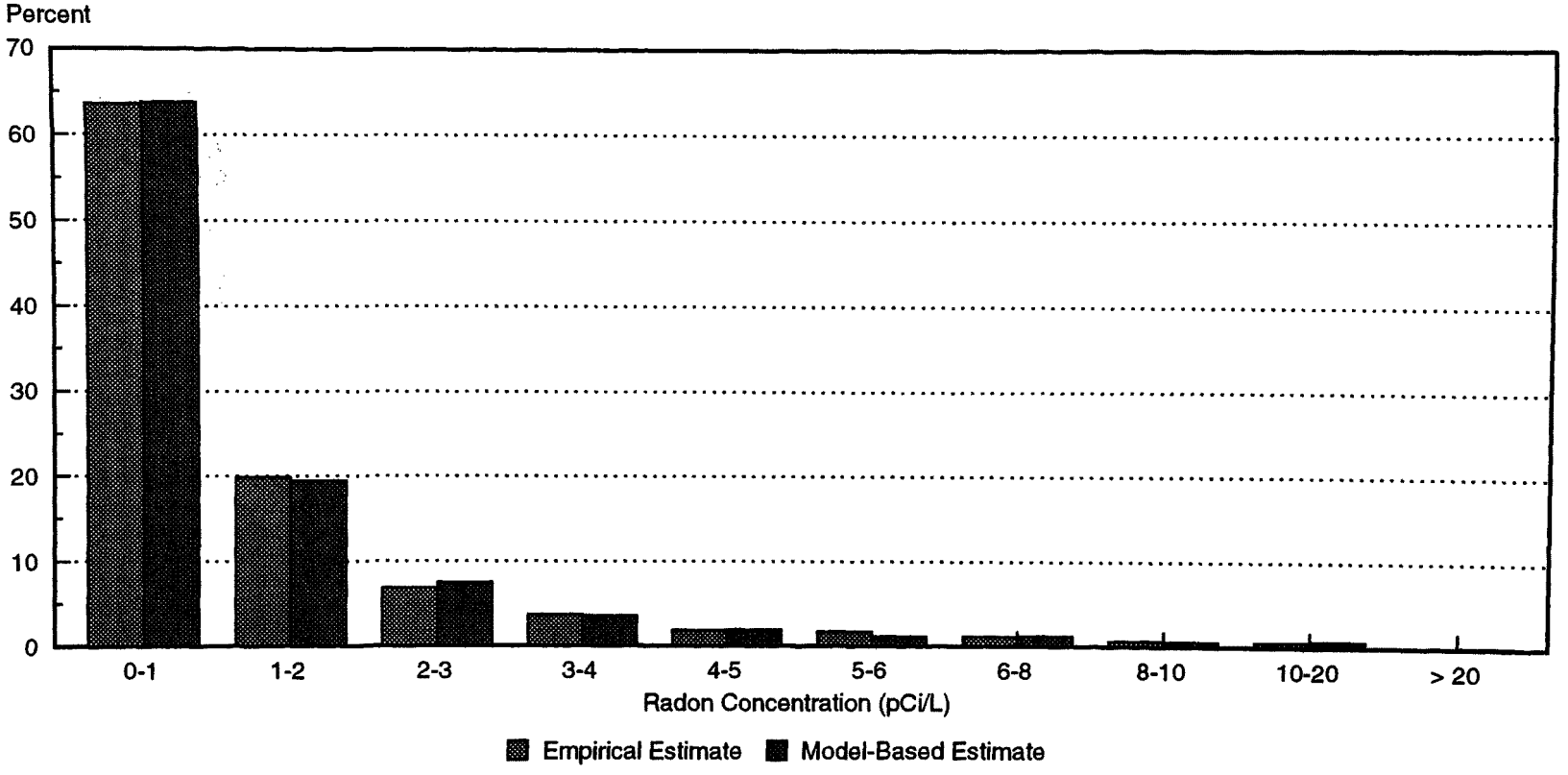
Radon Category (pCi/L)	National Population[1]			Ground-Contact Population[2]		
	Empirical Estimates (Percent)	Estimate Percent	Difference	Empircal Estimates (Percent)	Estimate Percent	Difference
0-1	63.61	63.79	0.18	59.17	59.65	0.48
1-2	19.87	19.44	-0.43	22.09	21.72	-0.37
2-3	6.85	7.44	0.59	7.75	8.43	0.68
3-4	3.66	3.56	-0.10	4.16	4.01	-0.15
4-5	1.85	1.94	0.09	2.08	2.16	0.08
5-6	1.72	1.16	-0.56	1.97	1.27	-0.70
6-8	1.15	1.23	0.08	1.32	1.32	0.00
8-10	0.64	0.58	-0.06	0.73	0.61	-0.12
10-20	0.59	0.72	0.13	0.68	0.71	0.03
>20	0.06	0.14	0.08	0.07	0.12	0.05
	100.00	100.00		100.00	100.00	
Key Thresholds						
> 4 pCi/L	6.01	5.77	-0.24	6.85	6.18	-0.67
>10 pCi/L	0.65	0.86	0.21	0.75	0.83	0.08
Assumed Parameters						
Geometric mean = median =		**0.67**			**0.77**	
Geometric standard deviation -		**3.11**			**2.92**	

[1] All homes included in the survey.

[2] All single-family units, except those that were 100 percent open underneath (such as unskirted mobile homes), and residences on the first floor in multi-family units.

EXHIBIT B-13

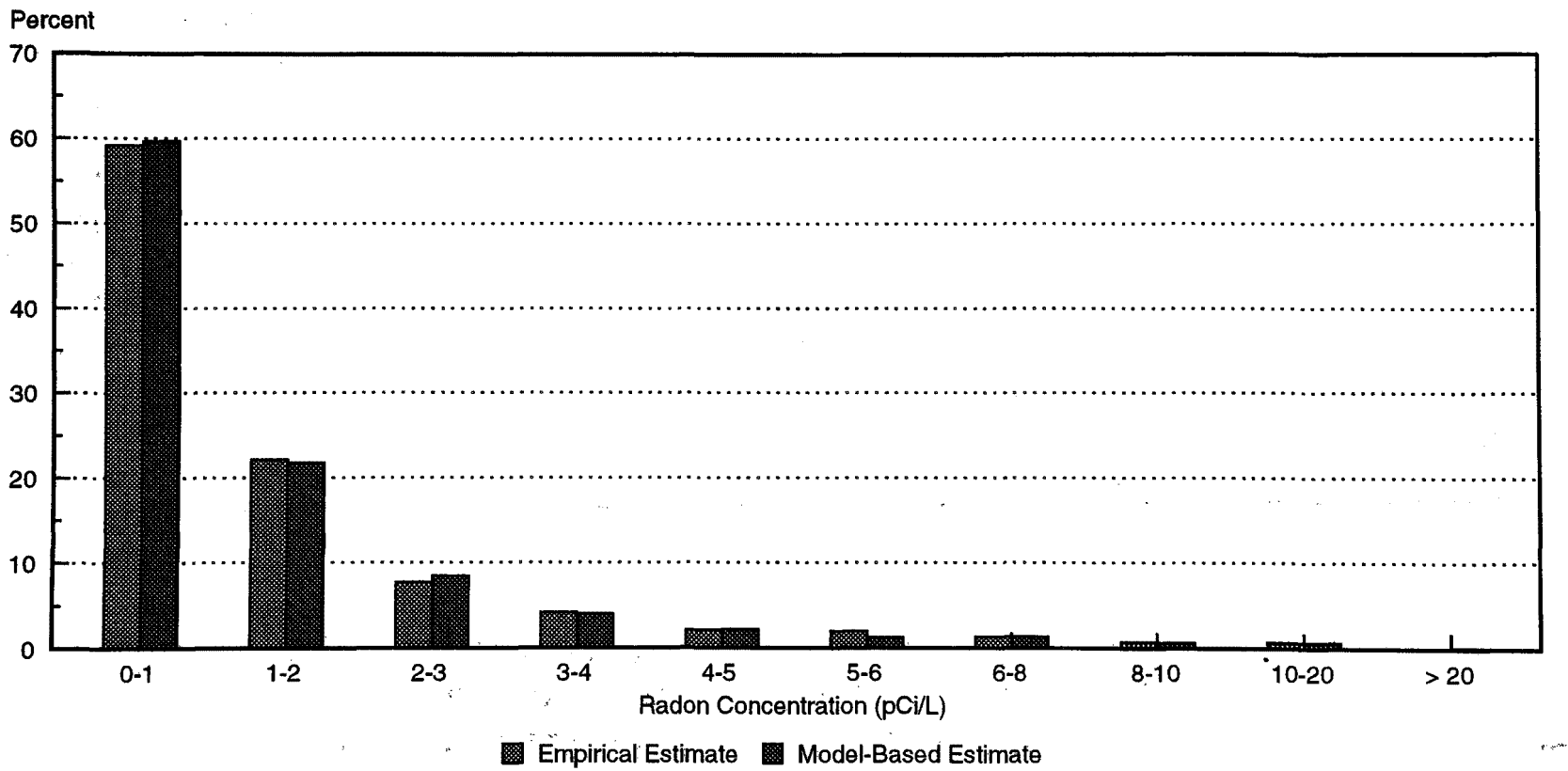
National Population Empirical Distribution With the Lognormal Distribution Modeled Using the Median and Best Range Estimator to Estimate the Lognormal Parameters



Note: Actual values are presented in Exhibit B-12.

EXHIBIT B-14

Ground-Contact Population Empirical Distribution With the Lognormal Distribution Modeled Using the Median and Best Range Estimator to Estimate the Lognormal Parameters



Note: Actual values are presented in Exhibit B-12.